Astron. Astrophys. 341, L79–L83 (1999)

ASTRONOMY AND ASTROPHYSICS

LETTER

Letter to the Editor

Proper motions of faint ROSAT WTT stars in the Chamaeleon region*,**

L.Terranegra[1], F. Morale[1,2], A. Spagna[3], G. Massone[3], and M.G. Lattanzi[3]

[1] Osservatorio Astronomico di Capodimonte, Via Moiariello 16, I-80131 Napoli, Italy
[2] Osservatorio Astronomico di Palermo "G.S. Vaiana", Piazza del Parlamento 1, I-90134 Palermo, Italy
[3] Osservatorio Astronomico di Torino, I-10025 Pino Torinese (TO), Italy

Received 7 August 1998 / Accepted 25 November 1998

Abstract. We present proper motions of 59 stars of the ROSAT All-Sky Survey (RASS) located in direction of the Chamaeleon star forming region (SFR) in the magnitude range B=5.1 - 17 mag. Proper motions of the fainter stars were newly derived utilizing survey Schmidt plates from the GSC II plate archive and from a set of special plates taken with the ESO Schmidt telescope. The vector point diagram (VPD) indicates that the certified WTT stars cluster away from the region occupied by the brighter pre-main-sequence stars (PMS) in Cha I. The distance to this new association is estimated at ~ 100 pc, sensibly smaller than the 150 pc generally assumed for the SFR. This yields an upper limit of 2 km s^{-1} for the velocity dispersion of this new kinematic group.

The de-reddened CM diagram of the group members suggest the WTT stars are still PMS objects, but older (3-30 Myr) and less massive than previous determinations. These revised age estimates, the newly derived group peculiar velocity, and current distance estimates to the Cha I/II/III complex would favour in-situ formation against that predicted by high velocity cloud models. Finally, based on a redetermination of the peculiar motions of stars and gas, we speculate that the whole SFR originated from the local Orion spur as a result of more classical mechanisms like interactions with the spiral arms.

Key words: astrometry – stars: fundamental parameters – stars: kinematics – stars: late-type – stars: pre-main sequence

1. Introduction

The Chamaeleon dark clouds complex is one of the most favorable star forming regions (SFR) in the southern sky for the study of proper motions of a good sample of PMS stars and related objects due to its proximity to the Sun (d≈ 150pc). Previous optical, X-ray and IR investigations of the Chamaeleon SFR revealed a significant number and a variety of PMS objects associated to its dark clouds, for example, classical T Tauri (CTTS) and Herbig Ae/Be stars (HAeBe), weak emission-line TTS (WTTS) X-ray and IRAS sources (Lawson et al. 1996 and references therein).

On the basis of the spectroscopic and photometric follow-up to the RASS in Chamaeleon, 77 new WTTS have been found (Alcalá et al. 1995, A95). The new WTTS are widely spread throughout the entire area studied, while the previously known PMS population tends to be mainly concentrated in the Cha I and Cha II dark clouds.

The true nature of the dispersed WTTS population observed in the direction of well-known SFRs is still matter of debate (Lépine & Duvert 1994, Sterzik & Durisen 1995, Feigelson 1996, Briceño et al. 1997). Astrometric data are essential to establish the observational test ground (e.g., stellar subgroups, velocity dispersions,...) for the star formation mechanisms proposed for these SFRs. Very recently, Frink et al. (1998) have discussed the proper motions of TTS present in the Hipparcos, ACT, and STARNET catalogs.

We started a program for the determination of the proper motions of the PMS population over an area of the sky covering about 160 $\square^\circ$ in the direction of the Chamaeleon-Musca SFRs. Here, we present results based on newly measured proper motions of members of the faint extension of the ROSAT WTTS sample present in the GSC S039 field (Lasker et al. 1990), centered at $12^{\rm h}04^{\rm m}41.8^{\rm s}$ and $-75^\circ14'42''$ (J2000) corresponding to b$^{II} = -12.72^\circ$, and l$^{II} = 299.70^\circ$. The discussion includes the proper motions of the brighter population of PMS stars extracted from the Hipparcos, ACT, and PPM catalogs and covering the whole extent of the SFR.

2. Observations and data analysis

In March 1995, six B-band plates and and six R-band plates were acquired on the Chamaeleon region with the ESO Schmidt telescope. These plates were digitized with the PDS microden-

Send offprint requests to: terranegra@astrna.na.astro.it

* Based on observations collected at the European Southern Observatory (Chile) and on data from the Hipparcos astrometry satellite.

** Table 1 is available only in electronic form at the CDS via anonymous ftp at 130.79.128.5.

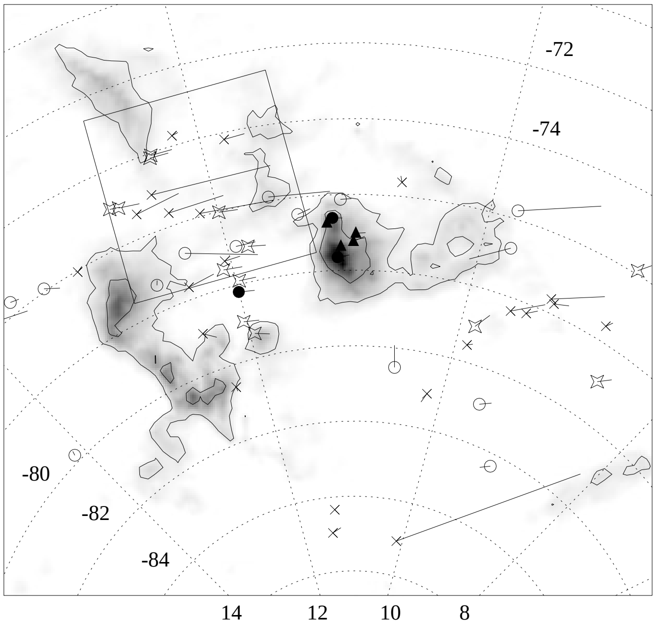

Fig. 1. The spatial distribution of the star sample superimposed to the Chamaeleon clouds system derived from the COBE 100 μm maps. For symbols see the text. The rectangle indicates the area covered by the S039 plate.

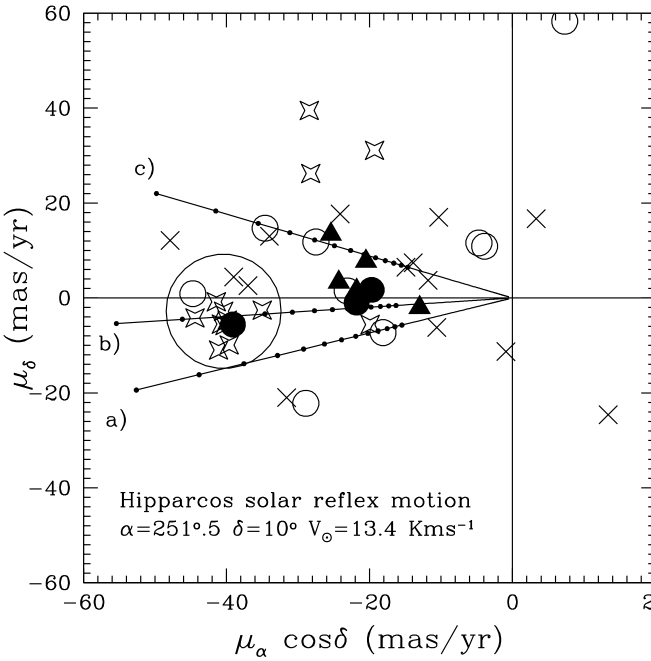

Fig. 2. The VPD diagram for the Chamaeleon stars. For the symbols see the text. The big circle indicates a group of program stars with similar proper motion components. The straight lines labelled *a, b* and *c* represent the contribution of the reflex solar motion to the proper motions at different distances (from 50 to 170 pc) and for three different directions on the sky. See text for more explanations.

sitometer of the Astronomisches Institut of the Münster University with 15-μm pixels. As first epoch material we used the digitized version (25-μm pixels) of UK-SERCJ Schmidt plate S039 as used for the construction of the GSC I (Lasker et al. 1990). The epoch difference between SERCJ and ESO plates is 19 years. Astrometry and photographic photometry were done with prototype code (Lattanzi et al. 1991; Spagna et al. 1996) being used for the construction of the Second Guide Star Catalog (GSC II) (Lasker et al. 1995). We derived proper motions for 130 000 stars detected down to the magnitude limit of B $\sim$ 19 in a region of $5^\circ \times 5^\circ$ centered on S039, in the Hipparcos system. The final proper motion error is $\sigma_\mu \simeq 5$ mas/yr in each component and for magnitudes V ≥ 10.

From our final catalog we matched 18 RASS stars from the list of A95. We also matched objects listed by Lawson et al. (1996). A search is being conducted for fainter PMS candidates on the magnitude limited sample and the results will be reported elsewhere. Proper motions of RASS and PMS stars from the same references and covering the entire Chamaeleon region were also searched in the following astrometric catalogues: ACT (Urban et al. 1997), PPM (Bastian & Röser 1993) and Hipparcos (ESA 1997). We found 37 objects in ACT, 25 in PPM, and 28 in Hipparcos. Data from these astrometric catalogs were combined with the fainter objects found in our catalog and the multiple entries were filtered according to catalog precision. The final list of 59 stars is shown in Table 1.

3. Stellar proper motions

The spatial distribution and the projected motions of our stars (Table 1) is shown in Fig. 1, where the symbols are as follows: *open stars* represent the *bona-fide* WTTS($\star$) classified as PMS objects from the high resolution spectra by Covino et al. (1997, C97); *crosses* are WTTS($\times$) classified from low resolution spectra by A95; *filled triangles* are CTTS, while *filled circles* are HAeBe stars (van den Ancker et al. 1997); finally, *open circles* represent field ROSAT stars classified as unrelated bright stars (UBS) by A95. The global west-ward flow depends on the fact that the solar reflex motion dominates over the tangential component of the still not negligible peculiar velocities of these young and relatively closeby stars.

The vector point diagram (VPD) of all but the few high values ($|\mu_\alpha \cos\delta| > 60$ mas/yr) in shown in Fig. 2.

Two concentrations of WTTS($\star$) and CTTS-HAeBe are apparent. In particular we note that all but four of the WTTS($\star$) share the same position in the VPD which is shown in the figure as the encircled region at approximately $\overline{\mu_\alpha \cos\delta} \simeq -40$ mas/yr, $\overline{\mu_\delta} \simeq -5$ mas/yr. This is also the case for most of the CTTS-HAeBe ($\overline{\mu_\alpha \cos\delta} \simeq -22$ mas/yr, $\overline{\mu_\delta} \simeq 2$ mas/yr) associated to the Cha I dark cloud, while the WTTS($\times$) and the field UBS stars show a larger proper motion dispersion.

The straight line labelled *a* in Fig. 2 shows the reflex solar motion in the direction (12^h, -77°) of the new group we calculated from the LSR solar velocity estimated by Dehnen & Binney (1998) from Hipparcos data. The small dots along the line indicate the value of reflex motion at increasing distances, from 50 pc (leftmost dot) to 170 pc at steps of 10 pc. The other two lines labelled b and c trace one the reflex solar motion toward Cha I (11^h, -77.5°) and the other that in the direction at $\alpha \simeq 9^h$ $\delta \simeq -77.5°$, which has been adopted as the mean direction for the three WTTS($\star$) with $\mu_\delta > 20$ mas/yr.

The fact that the clustered WTTS($\star$) and the three isolated WTTS($\star$) to the West have proper motion components about twice that of the PMS stars associated with Cha I suggests that the groups are at different distances; in particular, the *bona-fide* WTTS($\star$) seem to be sensibly closer to the Sun than the PMS stars associated with Cha I.

We note that all of the stars clustered in the encircled area of the VPD are also concentrated in the same region of the sky, $3.5° \times 5.5°$ in size, centered at $\alpha_{2000} \sim 12^h$ and $\delta_{2000} \sim -77°$ ($l \simeq 300°$, $b \simeq -14.5$) and, anticipating the content of the next sections, they all have similar photometric and trigonometric distances of ≈ 100 pc. The WTTS($\star$) sample has also homogeneous radial velocities[1] around $V_R \sim 13$ km s^{-1} (14 km s^{-1} including T-Cha), which is quite different from the radial component of the reflex solar motion (1.3 km s^{-1}) and that produced by the galactic rotation (-1.0 km s^{-1} for $d = 100$ pc). Furthermore, the dispersions of proper motions and V_R are comparable with the observational errors, much smaller than the intrinsic velocity dispersion expected for young field stars ($\approx$ 10 km s^{-1} for V_R and 20 mas/yr for μ_T at 100 pc). Therefore, there is significant evidence that these stars constitute a kinematical association of nearby stars. The association[2] West of the Cha II/Cha III complex and to the East of Cha I, includes 9 WTTS($\star$) (i.e. RXJ1150.4-7704, T Cha, RXJ1158.5-7754a, RXJ1159.7-7601, HD 104467, RXJ1204.6-7731, RXJ1219.7-7403, RXJ1220.4-7407, RXJ1239.4-7502), 2 WTTS($\times$) (RXJ1150.9-7411, RXJ1202.8-7718) and we argue for HD104237, a UBS star, to be a member of the group, as it is also a PMS star (it is a known HAeBe star, van den Ancker et al. 1997). Instead, we reject the second UBS star (HD103673) as a member of the association; the large Hipparcos parallax clearly indicates that HD103673 is a foreground star.

4. Distance determination

Thanks to Hipparcos, average trigonometric distances to both Cha I PMS and to our group can be estimated. (We excluded RXJ1224.8 -7503, LkH$_\alpha$332-21 and CD-76486 because of the large parallax errors). Three WTTS($\star$) (RXJ1158.5-7764, RXJ1159.7-7601 and T Cha) and one HAeBe star (HD104237) in our sample have Hipparcos parallaxes, which yield a weighted average distance of $\tilde{d} \equiv 1/\tilde{\pi} \simeq 108 \pm$ 5 pc (86 pc, excluding the HAeBe star). In Cha I, the two HAeBe stars, HD97300 and HD97048, and the CTTS member LKH$_\alpha$332-20 are also entries in the Hipparcos catalog. The derived average distance is $\tilde{d} = 175^{+20}_{-17}$ pc. Finally, we think that another early type (B7 V) UBS star, HD96675, spatially and kinematically close to the CTTS-HAeBe stars of Cha I, could be associated with that complex as the Hipparcos distance places it at 164^{+18}_{-16} pc; full membership awaits further investigations on its evolutionary nature.

The displacement from the reflex solar motion lines in Fig. 2 clearly depends on the *peculiar velocity* of the stars. Indeed a small component is generated by the differential galactic rotation. Such component amounts to $(\mu_\alpha \cos\delta)_{\rm gal} \simeq -4.4$ mas/yr and $\mu_\delta \simeq 0$ in the direction of our kinematic group, when utilizing the Oort constants A and B recently derived by Feast & Whitelock (1997) from the Hipparcos data.

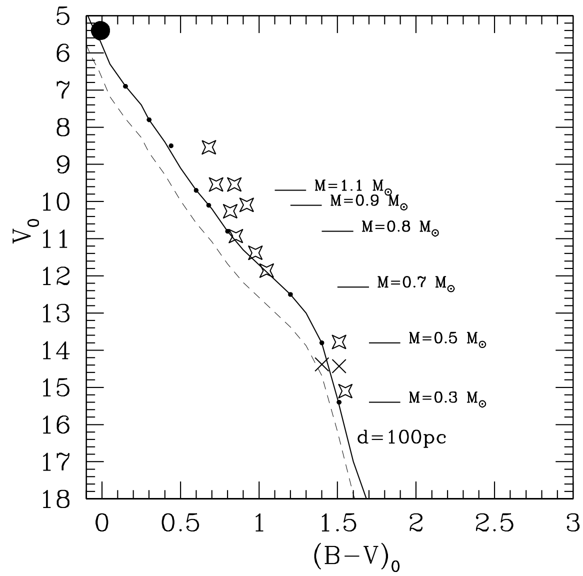

Fig. 3. The intrinsic color-magnitude diagram for the WTTS($\star$) association. The solid line is the ZAMS taken from Schmidt-Kaler (1982) and scaled to a distance modulus of 5 mag. The dashed line shows the ZAMS at the canonical distance of 140 pc. Also shown are the marks for different ZAMS masses.

5. The CM diagram and stellar ages

Fig. 3 shows the V$_0$ vs. (B-V)$_0$ diagram for the 12 members of the kinematic association, derived using spectral types, photometry and A_V data of A95, and Alcalá et al. (1997, A97). Also shown is the ZAMS taken from Schmidt-Kaler (1982) after scaling it to the adopted distance $d = 100$ pc. For most of the objects the location on this CMD seems compatible with their presumed PMS nature. Also, provided that the stars on this diagram are coeval, the observed residual scatter is within that expected from photometric errors and intrinsic effects like distribution of distances within the group, binarity, stellar rotation, and variability. It is interesting to note that the two M-type WTTS($\times$) which appeared within the encircled area of the VPD are retained as faint members[3] of the association.

[1] The radial velocity of T Cha measured by C97 is 20 $\pm$2 km s^{-1}. This value is marginally acceptable when compared to the quoted measurement error. In the same paper a radial velocity of 13 km s^{-1} for the gas (based on CO observations) in the direction of DC300.2-16.9 cloud associated with T Cha is reported.

[2] Some bright members of this association appear in the kinematic ensemble discussed in Frink et al. (1998) as *subgroup* 2, which includes 7 stars.

[3] RXJ1202.8-7718 was classified as a M0 star with a reddening of $A_V = 1.99$ by A97. We believe that a better classification for RXJ1202.8-7718 is M3/M4 with negligible reddening.

Table 2. Stellar parameters of the stars showed in the CMD.

Name	Type	$\log T_{\rm eff}$ (K)	L_* ($L_\odot$)	R_* ($R_\odot$)	M_* ($M_\odot$)	$\tau_{\rm age}$ (Myr)
RXJ1150.4-7704†	K4 ⋆	3.66	-0.43	0.9	0.83	30
RXJ1150.9-7411†	M4 ×	3.52	-1.10	0.9	0.22	3
T Cha ⋄	G8 ⋆	3.72	-0.20	1.0	0.95	30
RXJ1158.5-7754a ⋄	K4 ⋆	3.66	0.10	1.7	1.35	6
RXJ1159.7-7601 ⋄	K4 ⋆	3.66	-0.18	1.2	1.08	15
HD 104237†	A0 •	3.98	1.55	2.3	2.40	5
HD 104467†	G5 ⋆	3.74	0.57	2.2	1.60	7
RXJ1202.8-7718†	M3 ×	3.53	-0.75	1.3	0.28	3
RXJ1204.6-7731†	M2 ⋆	3.54	-0.90	1.0	0.35	5
RXJ1219.7-7403†	M0 ⋆	3.58	-0.58	1.1	0.70	7
RXJ1220.4-7407†	M0 ⋆	3.58	-0.39	1.4	0.70	3
RXJ1239.4-7502†	K2 ⋆	3.68	-0.09	1.3	1.18	10
RXJ1243.1-7458†‡	M3 ⋆	3.53	-1.44	0.6	0.25	15

Notes to Table: (†) Luminosity values by A97 rescaled to a distance of 100 pc or, (⋄) to the Hipparcos distances. For HD 104237 we used the data by van den Ancker 1997. (‡) Candidate ejected star.

The certified WTTS RXJ1243.1-7458, which is spatially but not kinematically close to the group, is also shown on the CMD[4]. Its proper motion puts the star in the VPD region close to the stars in Cha I. Could it be that this low mass star was ejected from the group? Our data would imply a velocity of $\sim$ 10 km s^{-1} tangentially and of $\sim$ 7 km s^{-1} radially, relative to the WTTS group. Direction and modulus of this velocity are consistent with the present locations of our stars and the ejection event taking place some $\tau \lesssim 0.5$ Myr ago. The estimated age of RXJ1243.1-7458 is 10 Myr and the photometric distance is $\approx$ 100 pc.

Table 2 reports the physical parameters of all the stars shown in Fig. 3 as derived from the $\log \rm L_*/L_\odot$, $\log \rm T_{eff}$data in A97 rescaled to the 100 pc or, to the Hipparcos distances. Ages, which ranges from 5 to 30 Myr, were estimated according to the evolutionary tracks from D'Antona & Mazzitelli (1994). For HD 104237 we used the data by van den Ancker (1997). All the stars in Table 2, but RXJ1243.1-7458, belong to the kinematic group.

6. Kinematical scenario

From the tabulated proper motions and adopting a mean distance $d = 100$ pc, the nine cluster WTTS(⋆) yield a tangential velocity dispersion σ_{V_T}=2 km s^{-1}, and σ_{V_T}=2.4 km s^{-1} if we include the two WTTS(×) and the HAeBe stars. These values are just upper limits to the actual velocity dispersion, because of the significant errors in the proper motions. Taking these into account the intrinsic dispersion should be very small and comparable to that observed for the Pleiades (Jones 1970), but quite lower than that found by Frink et al. (1997) for the WTTS in the central part of the Taurus-Auriga SFR. For the CTTS and HAeBe stars associated with the Cha I dark cloud we find the upper limit σ_{V_T}=3 km s^{-1}. This is consistent with the upper limits of 1 km s^{-1} found by Dubath et al. (1996) and by Jones & Herbig (1979) and Jones & Walker (1988).

The mean peculiar velocity of the group relative to the LSR, after removing the reflex solar motion and the differential galactic rotation at its distance is $(v_\alpha, v_\delta, v_r) \simeq (-4.4, +2.3, +12.7)$ km s^{-1} and $(U, V, W) = (+2.2, -13.3, -1.9)$, in galactic coordinates[5]. Adopting a distance of 175 pc for the CTTS, their mean peculiar velocity in the *same reference frame* is $(v_\alpha, v_\delta, v_r) \simeq (-1.5, +1.3, +13.9)$ km s^{-1} and $(U, V, W) = (+4.4, -12.8, -3.5)$, which is remarkably similar to the WTTS peculiar velocity.

The small W component does not seem to favour the predictions of the formation scenario from high velocity clouds (Lépine & Duvert, 1994), as such small velocities are not expected for stars close to the galactic plane. The group distance ($\sim$ 100 pc) and location ($b \simeq -15°$) yield a distance of ~ 25 pc Southward of the Sun, whose location is $z_\odot$ =10-20 pc above the plane (see e.g. Humphreys & Larsen 1995). Also, the scenario suggested by Lépine & Duvert, which predicts that gas and stars in the shock layer are inverting their vertical motion, is not consistent with the observed V_R and the fact that the youngest Cha I stars seem to be preceeding the older WTTS.

The direction of the peculiar velocity, and in particular the relatively high $|V|$, could suggest a completely different genesis with the SFR originating from the local Orion spur, although this fact needs further spatial and kinematical confirmations.

If we consider the SFR evolutionary models of Feigelson (1996), our co-moving group could correspond to stars generated from the same cloudlet, of which DC300.2-16.9, associated to T-Cha, could be the largest debris[6]. In this context, the connection with the three main molecular clouds becomes controversial given the large relative distances, and the *in-situ* formation scenario from an isolated cloud could be a better explanation for the origin of our group. In fact, Whittet et al. (1997) claim a distance to Cha I of 160 ± 15 pc (consistent with the parallaxes of its CTTS) and of 178 ± 18 pc for Cha II, while for Cha III (and DC300.2-16.9) a comparable distance of 140-160 pc is usually assumed. On the other hand, clouds and PMS stars in this complex seem to show similar peculiar velocities, which are different from the mean field stars; again, this could suggest some connections between nebular and stellar components. In particular, the mean heliocentric $V_R \simeq$ 13-14 km s^{-1} of the associated WTTS and of the local DC300.2-16.9 is only slightly less than the mean $V_R \simeq 15$ km s^{-1} that Dubath et al. (1996) measured for both the gas and the CTTS in Cha I. It is then plausible to think that the WTTS were formed by a turbulent cloudlet which escaped from the outer part of the SFR at least 10^7 yr ago, and moved toward the present direction of the Sun

[4] For this star we used $(B-V)_0 = 1.51$, which is the unreddened color of a M3V star. This choice is in good agreement with the U, V, R, and I magnitudes (and relative errors) listed by A95, and implies that the reported B magnitude is probably incorrect.

[5] U axis pointing toward the galactic center. T-Cha V_R was excluded from this average.

[6] See, e.g., the predictions in footnote 6 of Feigelson (1996).

with a mean velocity of a few km s^{-1} relative to the whole system.

If we knew the tangential velocity of the clouds, then a Westward tangential velocity could point to initial location of the cloudlet. Thus, *if* we assume that the young CTTS in Cha I are good tracers of the global gas kinematics, as indicated by their radial velocities, we can use their 3D velocity for studying the trajectory of this component, and this favours the direction from the Cha II/Cha III side.

Whatever the case, the relatively large separations are not consistent with simple stellar diffusion originating from the core of the molecular clouds with a thermal dispersion of $\sim$ 1 km s^{-1}. Note also that an alternative scenario which assumed a large cloud close to the WTTS group, at $\sim$100 pc, cannot be excluded *a priori*, because, e.g., the distance to Cha III given in Whittet et al. (1997) is not well established.

More definitive answers await for a better knowledge of the spatial and kinematical properties of the clouds, as well as for a more extensive and deeper proper motion study of the stellar component in the entire SFR.

Acknowledgements. We are grateful to the Referee, Dr. S. Frink, for her many useful comments. Thanks to Prof. A. Bruch and Dr. T. Schimpke for allocating PDS time to this project and for assistance during plate scanning. MGL, AS, and GM participation in the GSC II project is funded, in part, by the italian Council for Research in Astronomy. We are grateful to Prof. M. Capaccioli, to Prof. A Ferrari, and Dr. B. M. Lasker for their constant support. This research has made use of the Simbad data base, operated at CDS, Strasbourg, France.

References

Alcalá, J.M. et al., 1995, A&AS, 114, 109 (A95)
Alcalá, J.M. et al. 1997, A&A, 319, 184 (A97)
Bastian, U., Röser, S., 1993, PPM Catalog, Astronomisches Rechen-Institut, Heidelberg
Briceño, C. et al., 1997, AJ, 113, 740
Covino, E. et al., 1997, A&A, 328, 187 (C97)
D'Antona F., Mazzitelli I., 1994, ApJS, 90, 467
Dehnen, W., Binney, J.J, 1998, MNRAS, 298, 387
Dubath, P., Reipurth, B., Mayor, M., 1996, A&A, 308, 107
ESA, 1997, The Hipparcos and Tyco Catalogues, ESA SP-1200
Feast, M., Whitelock, P. 1997, MNRAS, 291, 683
Feigelson, E.D., 1996, ApJ, 468, 306
Frink, S. et al., 1997, A&A, 325, 613
Frink, S. et al., 1998, A&A, in press
Humphreys, R.M., Larsen, J.A, 1995, AJ, 110, 2183
Jones, B.F., 1970, AJ, 75, 563
Jones, B.F., Herbig, G.H., 1979, AJ, 84, 1872
Jones, B.F., Walker M.F., 1988, AJ, 95, 1755
Lasker, B.M. et al. 1990, AJ, 88, 1683
Lattanzi, M.G., Massone, G., Munari, U., 1991, AJ, 102, 177
Lawson, W.A., et al., 1996, MNRAS, 280, 1071
Lépine, J.R.D., Duvert, G., 1994, A&A, 286, 60
Schmidt-Kaler T.H., 1982, in Shaifers K., Voigt H.H, eds, Physical Parameters of Stars, Vol. 2b, Springer-Verlag, New York
Spagna, A. et al., 1996, A&A, 311, 758
Sterzik, M.F., Durisen, R.H., 1995, A&A 304, L9
Urban, S.E., Corbin, T.E., Wycoff, G.L., 1998, AJ, 115, 2161
van den Ancker, M.E., et al. 1997, A&A, 324, L33
Whittet, D.C.B., et al., 1997, A&A, 327, 1194